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A study of the cost effectiveness of minicomputers vs. main frames for structural analysis programs is described. It compares the performance of several finite element programs including SAP IV and SPAR. Most of the runs were performed with the Illinois Institute of Technology PRIME 400 minicomputer and the United Computing System UNIVAC 1100/81 main frame. Other computers were used selectively. The matrix of Structural problems included beam, plate and shell problems and static, dynamic and nonlinear analysis.

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THE COST EFFECTIVENESS OF MINICOMPUTERS VS. MAIN FRAMES FOR STRUCTURAL ANALYSIS PROBLEMS

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ABSTRACT

A study of the cost effectiveness of minicomputers vs. main frames for structural analysis programs is described. The study compares the performance of several finite element programs including SAP IV and SPAR. Most of the runs were performed with the Illinois Institute of Technology PRIME 400 minicomputer and the United Computing System UNIVAC 1100/81 main frame. Other computers were used selectively. The matrix of structural problems included beam, plate and shell problems and static, dynamic and nonlinear analysis.

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MINICOMPUTERS PROMISE CHEAPER, more widely available computing facilities, but they pose many problems, particularly to those with large calculations in mind. The smaller main memory means that users must make more use of disk I/O. Many minicomputers have a smaller word size (8 or 16 bits per word) with a devastating effect on accuracy. (Storaasli and Foster (1)* report 4 digit accuracy on a PRIME 400 for a medium-sized problem as compared to 8-13 digit accuracy on a CDC CYBER 173.) Longer elapsed times leave more room for machine hardware failures during a run. At Berkeley, Pearson reports some theoretical calculations required twenty-four hours or more, but the mean time between failures (MTBF) was also approximately twenty-four hours. Lack of adequate software libraries, debugging facilities, documentation and operations staff often hampers users of minicomputers.

Several past studies of the performance of minicomputers and main frames have concentrated on the machine cost aspect. Chemists have taken the lead in doing large scale calculations on small machines, perhaps because of their familiarity with the use of minicomputers for laboratory process control. Peter Lykos of the Illinois Institute of Technology organized an American Chemical Society Symposium on Minicomputers and Large Scale Computations in June, 1977 (2). Four of the papers from this meeting are particularly relevant to the present study since they involve large minicomputers with a cost in \$100,000 - \$200,000 range: Pearson et. al. (3); Norbeck and Certain (4); Wagner et. al. (5); and Freuler and Petrie (6). These papers have shown that based on machine cost alone minicomputers may be two to four times more cost effective than main frames. However, the National Resource for Computation in Chemistry Committee has concluded that "Minicomputers alone cannot meet the needs of the chemistry community" ((7), p. 1).

The structural analysis community is also experiencing a shift from main frames to minicomputers (e.g., Swanson (8)). For example, most of the major finite element packages are now available on the PRIME 400.

The users of structural analysis software on minicomputers have conducted several studies that point to the economic advantages of using such machines (e.g., Storaasli and Foster (1), Conaway (9)). These are based on data gathered by running structural analysis programs for various problems. The scope of the comparison was limited by the relatively small amount of data that was generated.

The purpose of the present study is to extend the previous studies in several directions. First, to use a wider mix of programs and problems for the comparison. Second, to include in the study several machines so that the results do not reflect only the charging algorithm at a particular installation. Last, the present study also attempts to further assess the human factors involved in such a comparison.

CHOICE OF STRUCTURAL ANALYSIS PROGRAMS AND PROBLEMS

Since the overwhelming majority of structural analysts use finite element methods, the present study is limited to such programs.

It is impossible to get a very accurate comparison of the performance of the mini and main frame systems without an exhaustive battery of test problems. However, we believe that by judicious choice of the type of problems and the type of structural analyses employed, one can obtain a reasonably reliable comparison of performance.

*Numbers in parentheses designate References at end of paper

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The following are the elements in such a comparison.

TYPE OF ANALYSIS-The type of structural analysis to be included in the tests must include the ones which are most commonly in use. This study includes the following:

(i) Linear static solution for displacement and stresses

(ii) Linear eigenvalue analysis - calculation of buckling loads and vibration modes

(iii) Nonlinear response due to large deformations and material nonlinearities

TYPE OF PROBLEM-Three structural problems are used:

(i) A simple cantilever beam

(ii) A plate with a hole

(iii) A stiffened cylinder

These problems are solved for the different analysis types. Several models are used for each problem ranging from a very crude model to a refined one. The number of degrees of freedom ranging from a few dozen for a crude model to more than a thousand for the refined one.

COMPUTER PROGRAMS-Three computer programs are used; these programs are:

(i) SAP IV - A general purpose finite element program developed at the University of California at Berkeley is probably the most widely used "free" (it costs $200.00) finite element code.

(ii) SPAR - A general purpose finite element program developed by W. D. Whetstone which serves as a prototype of a commercially developed code.

(iii) TWODEL - A special purpose finite element program developed by D. Malkus at IIT for large deformation analysis of 2 dimensional elasticity problems. It is a representative of in house codes.

THE COMPUTER PROGRAMS

SPAR - SPAR (10) is a general purpose finite element program developed by W. D. Whetstone for NASA, first at Lockheed and then at his own EISI company. The program has linear static analysis, eigensolutions for vibration and buckling and model response capabilities. It does not have nonlinear analysis or direct integration capabilities. The program has a public version which is distributed by the government through COSMIC. It also has a proprietary version called EAL (for Engineering Analysis Language). The public versions for the UNIVAC and CDC systems are maintained by the developer while the minicomputer versions (PRIME and VAX) are maintained by NASA. The proprietary version is available on all four systems but only in its executable version. Because of the expense of acquiring the proprietary version and the difficulty of instrumenting it without access to the source code, the public version was used for this study.

SPAR is a modular system composed of more than 20 small programs called processors. The processors communicate through a data base system which is also directly accessible to the user. (See Giles and Haftka (11) for more information.)

The public version of SPAR was installed on the UNIVAC without any problem. Installation on the PRIME was much more troublesome. Difficulties were due to some bugs in the PRIME version that had to be corrected and due to the virtual memory system of the PRIME that did not seem to work well for very large arrays. Additionally, the PRIME company issues new releases of the operating system quite often. Many times the older version of SPAR did not work with the newer operating system and the programs had to be recompiled and reloaded (a non trivial effort because SPAR is composed of so many individual programs).

SAP IV - SAP IV (12) is also a general purpose finite element program that has static, vibration and dynamic analysis capabilities. It has been developed by Wilson and his students at Berkeley and is available at nominal cost ($200.) to the public. It is probably the most widely used "free" finite element program. There are more advanced versions of SAP denoted as SAP V, SAP VI, etc. which are available at considerable cost ($9,000.00) from the University of Southern California. In the present study SAP IV is used.

The program was originally written for a CDC system. However, it has been converted to other systems. On the UCS UNIVAC 1100/81, there are three versions of SAP IV. However only one of these is working. The program can be compiled using UNIVAC's FORTRAN V compiler. An attempt to use the more efficient ASCII FORTRAN compiler was unsuccessful. A substantial change in the program and I/O format statements may be required to make SAP IV suitable for this compiler. There also is an absolute version of SAP IV which is supported by UCS and is available for problem solution.

The PRIME version of SAP IV was generated by Feeser of RPI. The first version of SAP IV which we received from the PRIME users' library was highly mutilated. Another tape was then obtained from RPI, Troy, after several months' wait. This tape had about 60 lines of code missing towards the end of the STRETR SUBROUTINE. Two following routines were also destroyed. Luckily this particular piece of code was correct on the earlier tape, and we were able to patch the code to make it work. Both times we received 800 BPI tapes. The PRIME installation at IIT has only a 1600 tape drive, however. The conversion was another non trivial task.

TWODEL - TWODEL (13) is a special purpose finite element program for two dimensional finite elasticity developed by Malkus at IIT. It is a relatively small program and was developed simultaneously for the UNIVAC and PRIME systems. The problem description is built into the program so that refining the mesh necessitates changes to program patches.

COMPUTERS AND CHARGING ALGORITHMS

A study on the cost effectiveness of a minicomputer and a main frame can be based on a detailed economic study of the costs of owning and operating each machine. Such a study is

feasible for a particular type of machine and a particular owner. It is, however, difficult to generalize to the broad category of minicomputers and main frames. The approach taken in the present work is to use the charging algorithms in several installations as the measure of the cost of running any of the selected problems. In most cases the charging algorithms are devised to recover the total cost of owning and operating the system, and in some cases to show profit.

Most of the runs were performed at the computer center at the Illinois Institute of Technology. The school operates its own PRIME 400 minicomputer and buys computing services in a UNIVAC 1100/81 from the United Computing System Corporation (UCS). A few runs were made also on the CDC CYBER 176 owned by a large manufacturing company (LMC) and on the UCS CDC CYBER 176. The performance of the programs on the first three computers was used to predict performance on a few additional systems. The following is a brief description of the computer systems that were used in this study, their charging algorithms and the method used to predict performance on them.

IIT - PRIME 400 - The PRIME 400 is a medium size minicomputer which is used at IIT to support interactive computing. The present configuration has 1.25 Megabytes of memory and two disk drives. The system is very busy from about 9 AM Monday through Saturday with about 20 to 30 users. However, most of the users are not CPU intensive. As a result the CPU intensive structural analysis programs often show very good response times even during the day. In running on the PRIME 400 it was found that the response time and I/O times are quite sensitive to the number of users while the CPU time is not. To account for the variability runs were performed for several user environments on the PRIME and the performance averaged.

The charging algorithms for the system is given in Table 1 (considerable discounts are available at non-business hours). While most of the users do not pay the charges, some do. The charging algorithm is intended to cover the total cost of owning and operating the system and providing user support. Total billings are about $16,000.00 a month.

NASA - LANGLEY RESEARCH CENTER PRIME 400 - The NASA Langley Computer Center operates several minicomputers including a PRIME 400 computer. The charging algorithm (see Table 1) was devised to recover the capital and operating costs. The NASA PRIME 400 supports a small number of users; however, the users run more CPU intensive jobs than the IIT users.

Based on these considerations it was assumed that program performance is similar on the IIT and NASA systems. The cost of running a job on the NASA PRIME was calculated based on this assumption.

NASA - LANGLEY RESEARCH CENTER CYBER 173 - The NASA Langley Research Center operates several CDC main frames including two CYBER 173 computers which are used to support interactive computation. The charging algorithm is devised to recover capital and operating expenses.

One of us (Haftka) has an extensive experience using the SPAR program on both the IIT and NASA systems. Based on this experience the following assumptions were used to predict cost on the NASA CYBER 173.

1. The CPU time on the CYBER 173 is 1.5 times that of the CPU time on the UNIVAC 1100/81.

2. The I/O charges are calculated based on the number of reads and writes from the SPAR data base available in the SPAR output. It was assumed that these numbers are similar for both systems, and that the charge per disk access is 1.1 times the minimum charge per access. This is based on the feature of the charging algorithm which is relatively insensitive to the number of words in each read or write operation.

3. The amount of core required is assumed to vary from 70K octal for the smallest number of nodes to 120K for the largest number of nodes.

4. Based on the above considerations the cost of running SPAR on the NASA CYBER 173 is

$$\text{Cost} = (1 + 0.048A)(0.0136T_1 + 0.003ni\emptyset)$$

where

T_1 = UNIVAC 1108/81 CPU time (sec)

$ni\emptyset$ = combined number of disk reads and writes reported by SPAR

A = core storage (in units of 10K octal words)

LARGE MANUFACTURING COMPANY CDC CYBER 176 - A few runs of SPAR were made on a CYBER 176 which is owned by a large manufacturing company. The charging algorithm is given in Table 1. It appears to be fairly high on CPU and low on I/O and core storage charges. In predicting costs on this machine it was assumed that CPU times can be predicted from the UNIVAC 1100/81 results based on published data (14) rating the UNIVAC 1100/81 at 1800 KOPS and the CYBER 176 at 9300 KOPS. It was assumed that the ratio of I/O time to CPU time is the same on both machines. Because the I/O cost on the CYBER 176 is low, even a large error in this assumption is not expected to change the cost much. For SAP IV the data for the UCS CYBER were used for the LMC CYBER estimates.

CONCORDIA COLLEGE COMPUTER NETWORK (CCCN) - CCCN provides administrative, instructional and research computing services to a large number of educational institutions. The service includes a large software development staff and the charges are computed to recover costs of operating the center. Interactive and batch services are provided by a UNIVAC 90/80 main frame installed in December, 1980. The UNIVAC 90/80 is roughly equivalent to an IBM 370/158 in raw processing power. The prediction of costs of running on the CCCN UNIVAC 90/80 were based on the charging algorithm given in Table 1 with the following assumptions.

1. CPU times are 2.25 longer than on the UNIVAC 1100/81. This is based on published data (14) rating the UNIVAC 1100/81 at 1800 KOPS and

the UNIVAC 90/80 at 900 KOPS.

2. Core requirements were estimated at 200 K bytes for the small problems and at 300 K bytes for the large problems.

IIT RESEARCH INSTITUTE VAX 11/780 - The IIT Research Institute (IITRI) operates a DEC VAX 11/780 with 3 megabytes of core memory and 650 megabyte disk space. The IITRI computer is not intended for uses involving much "number crunching" so that it does not have a floating point processor. It is not heavily loaded so that time is available to outside users. The charging algorithm is given in Table 1.

RESULTS

BEAM PROBLEM - A cantilever beam was modeled by plane beam elements (E24 elements in SPAR) and three vibration modes and frequencies were calculated using the SPAR program. The number of nodes was varied from 5 to 600 and with three degrees of freedom per node; the maximum number of degrees of freedom is 1800. However, even for 600 nodes the problem is not costly to run because of the very small band width associated with a one dimensional problem.

For small problem sizes (up to 25) the problem can be run in single precision. For larger number of nodes the limited double precision option in SPAR (double precision used only for assembling the stiffness matrix) must be employed.

This simple problem exposed a bug in the PRIME version of SPAR. The program could not calculate more than two vibration modes and frequencies. The problem occurred in the subspace iteration method and seemed to indicate that the initial vectors generated by a random number routine were not linearly independent. On the UNIVAC there was no problem to get the required three lowest frequencies.

The CPU, I/O, response times and cost for the beam problem are given for the UNIVAC 1100/81 in Table 2 and for the IIT PRIME 400 in Table 3. The cost of running the problems is calculated based on the prime time rate. The total cost proved to be very close to a linear function of the number of nodes for both computers. It was therefore possible to predict accurately the cost of 600 node run by extrapolating the cost of the 5-280 node runs. It is therefore assumed that the 5-600 node results can be used safely to extrapolate cost up to 1200 nodes. The actual and predicted cost results for both computers are also shown in Figure 1. From Tables 2 and 3 and Figure 1 it is clear that the beam runs are about twice as expensive to run on the UCS UNIVAC 1100/81 as on the IIT PRIME 400. The response time or turnaround time is favorable on the PRIME for the small problems but the UNIVAC is quite faster for the larger problems.

The performance of other computers for the beam problem was actually measured or estimated and the results are summarized in Table 4. It can be seen from Table 4 that the costs of running the problem on the NASA PRIME 400 are comparable to those at IIT. However, comparison with the other main frames reveal costs which are significantly lower than those of the UNIVAC 1100/81. Part of the difference may be due to the fact that the CDC CYBER machines are not operated for profit and do not have marketing expenses. The low cost on the CYBER 176 reflects low I/O charges on that machine compared to the NASA CYBER 173. On the CYBER 176 about $1.40 of the $2.24 cost is CPU related and the rest is I/O related cost. On the NASA CYBER 173 only $0.57 of the $8.60 cost is CPU related and the rest is I/O related. In assessing the total cost results in Table 4 the main difference is not between minicomputer and main frames. Rather it is between the service bureau computers (the two UNIVAC machines) and the user owned machines which have lower charges.

PLATE PROBLEM - A rectangular plate with a hole was modeled with quadrilateral plane stress finite elements. Because of symmetry only one quarter of the plate is modeled, see Figure 2. The plate is subjected to uniform loads and the stresses in it are calculated for the cases where the number of nodes varies between 35 and 594. The problem was run with the SPAR and SAP programs. CPU and I/O times response times and cost on the UNIVAC 1100/81 are given. From Tables 5 and 6 we see that the performance of the two programs is similar. The turnaround time on the UNIVAC is much better than that of the PRIME. The cost on both machines are comparable.

It is possible to predict the cost of the 594 node run from the first four runs by a quadratic polynomial with less than 10% error. It is expected, therefore, that it is possible to use the data in Tables 5 and 6 to predict with such a polynomial the cost of running problems up to about 1200 nodes. The cost data and the predictive curve are given for SPAR in Figure 3 and for SAP IV in Figure 4. It is seen from Figures 3 and 4 that the cost of the plate problems increases much more rapidly on the PRIME than on the UNIVAC. VAX results show a similar behavior.

The results from Tables 5 and 6 were used to predict performance on other computers and the results are given in Table 7. The results in Table 7 do not seem to indicate a difference between the minicomputers and the main frames but rather that the cost on user owned CDC machines is substantially lower than on the other computers.

The plate problem was now analyzed for large deformations using the TWODEL program. The plate was assumed to be made of rubber modeled by the Mooney-Rivlin law with $c_1 = 0.3 \times 10^8$ psi and $c_2 = 0.6 \times 10^8$ psi. The plate is stretched to twice of its original length and the solution performed with 10 incremental steps. CPU and I/O times, response time and cost for the UNIVAC 1100/81 are given in Table 8 and for the PRIME 400 in Table 9. The TWODEL program uses only incore operations so that the program size is very sensitive to the problem size. The required core size on the UNIVAC is also shown in Table 8.

As can be seen from Figure 5 which compares the cost of running TWODEL for various problem sizes, the problem is much cheaper to run on the PRIME 400 than on the UNIVAC 1100/81. Furthermore, the 289 node problem was the largest that

could be run on the UNIVAC 1100/81 because of core limitations. The PRIME 400 with its virtual memory could handle larger problems. The excellent performance of the program on the PRIME 400 is attributed to two factors.

First, the large core requirements on the UNIVAC 1100/81 are very expensive (fifty percent of the cost of the 289 run was core cost). Second, the program was written by the developer on both machines. As a result it does not suffer from the deterioration in performance that afflicts programs that have been converted to different machines by users who are not as knowledgeable about the program as its developer. This applies to the SPAR and SAP programs. A comparison of the CPU times on the PRIME 400 and the UNIVAC 1100/81 for the plate problem shows the following ratios. The PRIME 400 CPU times are 7-15 times longer for SAP IV, 7-13 times longer for SPAR, but only 5-8 times longer for TWODEL. The core sizes given in Table 8, were used to predict performance on other computers. For CDC machines it is expected that there would be no need for double precision: The core requirements were accordingly slashed by 1.8 and the same ratio was used for the CPU times. The comparison with other computers is given in Table 10. It is seen that the cost on the two UNIVAC computers is very high and the cost on the LMC CDC computer is very low compared to the PRIME 400.

STIFFENED CYLINDER PROBLEM - A stiffened cylindrical shell, see Figure 6, modeled by plate and beam elements. Because of symmetry only one half of a 90° segment of the shell was modeled. The lowest four vibration frequencies and the buckling load of the cylinder were calculated using the SPAR program. Three models were used with 5x5, 10x10 and 15x15 grids of elements. This corresponds to 36, 121 and 256 nodes, respectively. The largest model has about 1500 degrees of freedom.

The cylinder problem revealed two bugs in the SPAR program. The stress analysis which is a preliminary to the buckling calculation was not correct when combined membrane-bending elements (type E43 in SPAR) were employed. As a result it was necessary to use twice as many plate elements; pure membrane elements (type E41) and pure bending elements (type E42). Unfortunately, the mass matrix was not calculated properly with this replacement. As a result we had to perform the calculations in two separate runs, one using double elements for buckling analysis and one using combined elements for the vibration analysis. This did not increase the cost of the run substantially but was an inconvenience for the analyst.

The result of CPU and I/O times, response time and cost are given in Table 11 for the UCS UNIVAC 1100/81 and in Table 12 for the IIT PRIME 400. Comparison with other computers is given in Table 13 for the largest problem of 256 nodes. It can be seen that for this problem the performance of the PRIME 400 is dismal and that of the CDC very good.

The experience with the same problem with the SAP IV program was quite different. The PRIME 400 version ran with no difficulties while the UNIVAC 1100/81 and the UCS CDC CYBER 7600 encountered convergence difficulties. These difficulties were bypassed by change of parameters for the 36 node problem but difficulties remained for the larger problems. It is possible that these could be resolved too, but it required a degree of familiarity with the SAP IV program that the authors do not have.

The cylinder problem was next analyzed for transient response by direct integration on the SAP IV program. The response to an oscillating normal load was calculated for forty time steps (each of 0.0125 sec). Since the cyclinder problem is rather expensive, it was not run for all sizes on all computers. For the 256 node problem the amount of scratch disk space required by the program was of the order of five megabyte on the PRIME 400 and was impossible to run in periods when the disk utilization was high. On the UNIVAC the program automatically switches to use magnetic tapes in such a situation. This results in very large I/O times and high charges. The results are given in Table 14. This problem illustrates best how the problem size influences resource consumption and charges. That is, for the smallest problem overhead charges dominate which are lowest on the minicomputers and make them cheaper. For the medium sized problem CPU consumption is dominant and the main frame is cheaper, whereas for the large problem the additional core requirements were accommmodated more cheaply by the computers with virtual memory.

CONCLUDING REMARKS

A study of the performance of structural analysis programs on main frame and minicomputers has not demonstrated a clear cut advantage of either type of computer. Difficulties were encountered on both types of computers for different problems. For the minicomputers some of these difficulties arose from portability problems when structural analysis packages that were developed on main frame computers were converted imperfectly to minicomputers. Another factor is that software is easier to get for a main frame. As the problem sizes increased, the minicomputers showed reduced efficiency for those programs which were not developed for them; but on the other hand, some of the main frames were unable to run those problems adequately, too. The minicomputer clearly outperformed the main frame for the one program which has been developed on the minicomputer.

When costs are compared there was also not much difference between the main frames and the minicomputers except in the case of the user owned CDC CYBER machines. This probably reflects a highly competitive marketplace where the decrease in the cost of raw computation has stimulated an increase in programming and computer services offered. Main frames no longer hold a monopoly on structural analysis software (or most other software for that matter) and have to price their services adequately to compete with the minicomputers.

If one is merely interested in the cost,

the user owned machines which just charge to cover their costs naturally fare better than machines owned by organizations which need to make a profit and may have marketing and other related expenses. This reduces the problem to one of microeconomics and price theory (15).

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Table 1

Charging Algorithms (dollars)

1. IIT PRIME 400	$0.02\ (T_1 + T_2) + T_3$ T_1 = CPU time (sec) T_2 = I/O time (sec) T_3 = wall time (hours)
2. NASA Langley Research Center - PRIME 400	$30T_1 + 15T_2$ T_1 = CPU time (hours) T_2 = wall time (hours)
3. UCS UNIVAC 1100/81	$0.18T_1 + 0.0011A(T_1 + T_2)$ T_1 = CPU time (sec) T_2 = I/O time (sec) A = (core/512) words
4. Concordia College UNIVAC 90/80	$(0.156 + 0.0000248A)T$ T = CPU time (sec) A = core (kilobytes)
5. Large Manufacturing Company CDC CYBER 176	$0.2T_1 + 0.0003A\ (T_1 + T_2) + .03 * T_2$ T_1 = CPU time (sec) T_2 = I/O time (sec) A = core (kilowords)
6. NASA Langley Research Center - CDC CYBER 173	See section on "Computers and Charging Algorithms," pages 2-4.
7. UCS CDC CYBER 176	Confidential
8. IIT Research Institute VAX 11/780	$0.05T_1 + 5T_2$ T_1 = CPU time (sec) T_2 = connect time (hours)

Table 2

Beam Results on the UCS UNIVAC 1100/81 Using SPAR

Number of Nodes	CPU (sec)	I/O Time (sec)	Turnaround Time (min)	Cost (dollars)
5	5.06	15.77	3:21	1.83
25	5.74	16.12	2:50	2.07
60	7.07	18.17	6:04	2.66
90	8.30	19.79	2:41	3.16
125	10.29	22.81	4:26	4.07
280	16.70	32.59	7:17	6.90
450	22.52	41.73	3:16	9.53
600	30.73	59.68	7:45	13.80
1200 *	60.76	72.10	8:55	30.89

* predicted

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Table 3

Beam Results on the IIT PRIME 400 (Averages)

Number of Nodes	CPU Time (sec)	I/O Time (sec)	Response Time	Cost (dollars)
5	14.70	17.68	1:03	0.67
25	19.33	17.43	1:03	0.73
60	30.65	28.45	2:37	1.2[illegible]
90	37.07	22.84	1:57	1.23
125	47.82	37.25	6:02	1.80
280	94.24	63.11	5:41	3.25
450	141.07	132.87	11:04	5.16
600	197.38	125.76	13:47	6.68
1200 *	422.92	262.02	26:36	14.14

* predicted

Table 4

Comparison of the 600 and 1200 Node Beam Problems on Various Computers
(1200 Node Results Are Given in Parentheses)

Computer	CPU (sec)	I/O (sec)	Turnaround Time (min)	Total Cost (dollars)
IIT PRIME 400+	* 197.38 (422.92)	125.76 (262.02)	13:47 (26:36)	6.68 (14.14)
NASA LRC PRIME 400*	197.38 (422.92)	125.76 (262.02)	13:47 (26:36)	5.08 (10.17)
UCS UNIVAC 1100/81	* 30.73 (60.76)	59.68 (72.10)	7:45 (8:55)	13.80 (30.89)
NASA LRC CYBER 173*	46.1 (91.14)			8.60 (20.78)
LMC CYBER 176	* 6.05 (11.76)	24.5 (35.4)	--	2.24 (3.98)
Concordia College UNIVAC 90/80*	69.14 (136.71)	--	--	11.13 (22.34)

* estimated

\+ average

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Table 5

Plate Linear Analysis with SPAR on Various Computers

Number of Nodes	CPU (sec)	I/O (sec)	Turnaround (min:sec)	Cost (dollars)
UNIVAC 1100/81				
35	4.80	14.25	1:27	1.69
72	6.98	15.55	1:44	2.46
143	11.89	18.36	2:08	4.22
285	24.46	25.27	2:48	8.69
594	60.58	44.78	4:36	21.94
1200	170.27	102.31	9:23	62.89
IIT PRIME 400				
35	32.11	19.18	1:23	1.05
72	58.40	29.91	2:58	1.81
143	123.14	44.96	4:30	4.18
285	285.14	123.65	8:56	8.39
594	805.06	679.25	41:24	28.71
1200	2500.40	1370.10	144:15	126.21

Table 6 - Plate Linear Analysis with SAP IV on Various Computers

Number of Nodes	CPU (sec)	I/O (sec)	Turnaround (min:sec)	Cost (dollars)
UNIVAC 1100/81				
35	4.52	1.11	1:13	0.90
72	6.77	1.93	1:51	1.56
143	11.55	3.54	2:12	2.97
285	25.38	8.19	3:08	7.15
594	78.59	26.94	10:08	23.61
1200*	316.58	122.14	18:54	98.67
IIT PRIME 400+				
35	30.82	25.65	7:55	1.26
72	66.40	41.15	11:00	2.33
143	166.12	47.15	21:27	4.62
285	396.80	82.61	25:32	10.01
594	1186.52	216.10	54:08	28.95
1200*	3791.00	685.74	112:12	108.60
UCS CYBER 176				
35	.54	1.88	--	0.96
72	1.00	3.08	--	1.92
143	1.69	4.48	--	3.36
285	4.10	10.82	--	7.20
594	11.96	38.21	--	21.60
1200*	32.96	99.18	--	70.81
IIT Research Institute VAX 11/780 +,**				
35	10.36	--	0:25	0.52
72	20.94	--	0:30	1.05
143	59.62	--	3:30	2.98
285	182.43	--	5:28	9.12
594	568.33	--	12:41	28.42

* estimates
\+ averages
** jobs were run in batch mode, no connnect time charges

Table 7

Comparison of the Cost of Linear Analysis of the 594 (1200) Node Plate Model on Various Computers (in Dollars)

Computer System	SAP IV 594	SAP IV 1200	SPAR 594	SPAR 1200
IIT PRIME 400+	28.95	108.60	28.71	126.21
NASA LRC PRIME 400*	23.38	59.64	17.06	56.90
UCS UNIVAC 1100/81	23.61	98.67	21.94	62.89
NASA LRC CYBER 173*	**		6.84	18.90
LMC CYBER 176*	4.23	11.39	2.85	7.82
Concordia College UNIVAC 90/80	28.98	116.42	22.28	69.57
UCS CYBER 176	21.60	70.81	--	--
IIT Research Institute VAX 11/780	28.42	**	--	--

+ average of several runs
* predicted results
** data insufficient for prediction

Table 8

Plate Nonlinear Analysis on the UCS UNIVAC 1100/81

Number of Nodes	CPU Time (sec)	I/O Time (sec)	Core Storage (Kwords)	Turnaround Time (min)	Cost (dollars)
35	19.97	0.35	22.9	32:47	4.61
72	54.15	0.66	28.4	38:01	13.13
143	156.91	1.29	42.5	55:10	42.68
289	549.69	1.78	76.0	137:21	189.33
600*	2030.59	3.59	175.7	650:43	1151.80

* estimates

Table 9

Plate Nonlinear Analysis on the IIT PRIME 400

Number of Nodes	CPU Time	I/O Time (sec)	Response Time (min)	Cost (dollars)
35	156.01	2.74	7:08	3.29
72	379.95	3.81	10:09	7.84
143	978.05	19.47	29:59	20.45
289	2693.59	69.70	70:50	56.44
600*	8693.00	287.91	204:14	193.06

* estimates

Table 10

Comparison of the Cost (in Dollars) of Nonlinear Analysis of the 289 and 600 Node Plate Models on Various Computers Using the TWODEL Program

Computer System	CPU Time (sec) 289	CPU Time (sec) 600*	Core+ 289	Core+ 600*	Cost (dollars) 289	Cost (dollars) 600*
IIT PRIME 400	2694.	8693.	--	--	56.44	193.06
NASA LRC PRIME 400*	2694.	8693.	--	--	40.13	123.50
UCS UNIVAC 1100/81	550.	2030.6	76.0	175.7	189.33	1177.66
LMC CDC CYBER 176*	58.8	217.1	42.2	97.6	12.52	49.80
Concordia College UNIVAC*	1238.	4570.7	320.	740.	203.03	794.20

* estimates; + UCS UNIVAC 1100/81 and LMC CDC CYBER 176 core requirements are given in K words. Concordia College UNIVAC core requirements are given in K bytes.

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Table 11

Cylinder Buckling and Vibration Analysis on the UCS UNIVAC 1100/81

Number of Nodes	CPU Time (sec)	I/O Time (sec)	Turnaround Time (min)	Cost (dollars)
36	27.28	19.34	7:09	7.36
121	110.65	28.16	10:11	29.21
256	302.59	48.45	19:52	79.97

Table 12

Cylinder Buckling and Vibration Analysis on the IIT PRIME 400

Number of Nodes	CPU Time (sec)	I/O Time (sec)	Turnaround Time (min)	Cost (dollars)
36	579.93	343.28	64	19.53
121	3197.10	1184.54	156	90.23
256	10784.0	6589.98	774	360.38

Table 13

Comparison of the 256 Cylinder Problem on Various Computers

Computer	CPU Time (sec)	I/O Time (sec)	Total Cost (dollars)
IIT PRIME 400+	10784	6590	360.38
NASA LRC PRIME 400*	10784	6590	283.37
UCS UNIVAC 1100/81	302.59	48.45	79.97
Concordia College UNIVAC 90/80*	680.8	--	110.96
LMC CDC CYBER 176*	58.2	24.2	12.64
NASA LRC CYBER 173*	453.9	--	29.55

Table 14

Direct Integration Transient Response of Stiffened Cylinder

Number of Nodes		CPU Time (sec)	I/O Time (sec)	Turnaround Time (min)	Cost (dollars)
36 -	PRIME 400	157.1	19.1	4	3.59
	UNIVAC 1100/81	12.3	10.7	4	6.12
	CYBER 176	7.8	26.6		14.40
	VAX 11/780	65.12	--	3.1	3.26
121 -	PRIME 400	2795	528.8	147	68.93
	UNIVAC 1100/81	133.7	66.1	14.9	42.50
	VAX 11/780	1049.38	--	28.7	52.47
256 -	PRIME 400	10411	1658	470	249.20
	UNIVAC 1100/81	493.8	2423.2	120	556.70

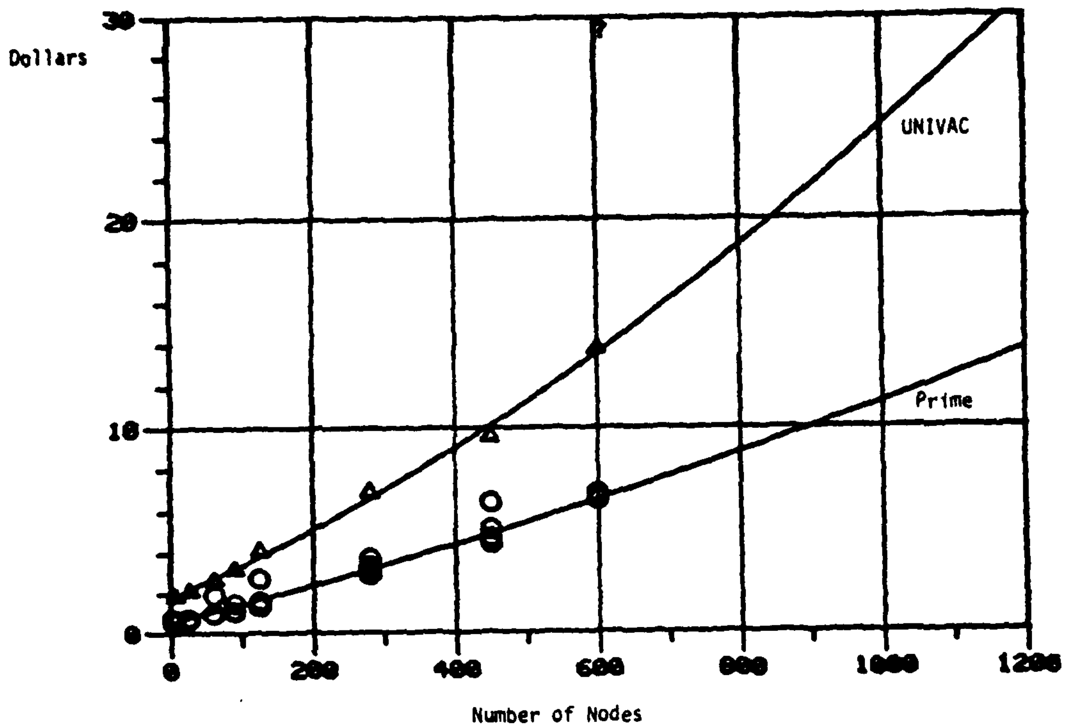

Fig. 1 - Comparison of total cost for beam problem using the SPAR program

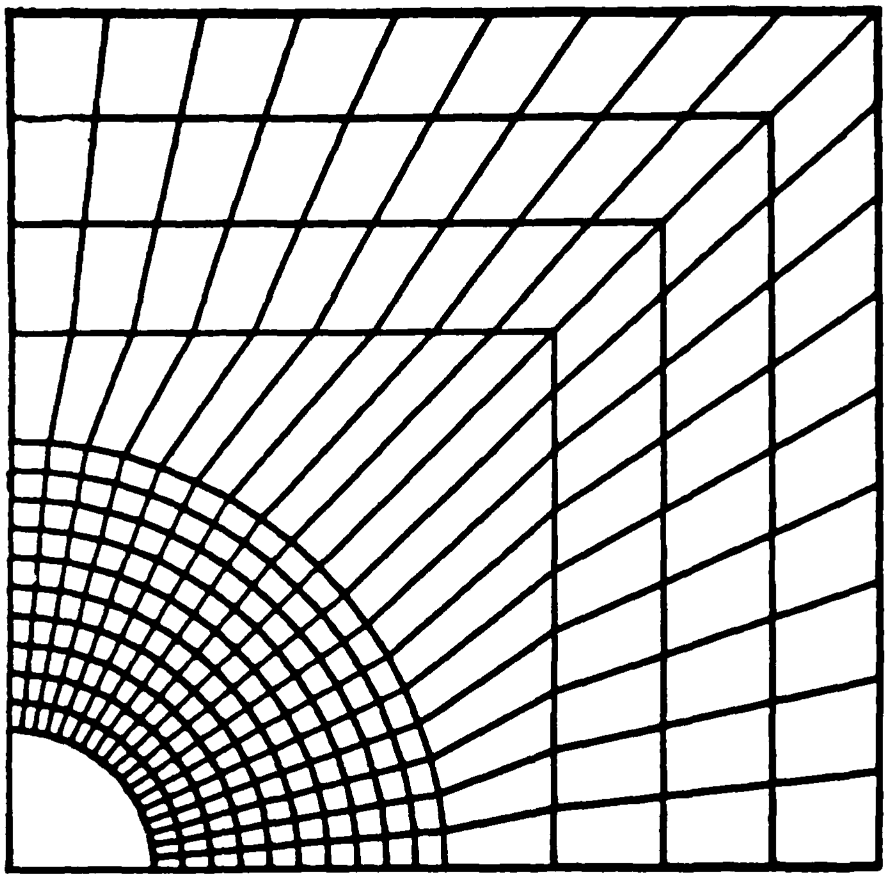

Fig. 2 - A typical model for plate with hole problem

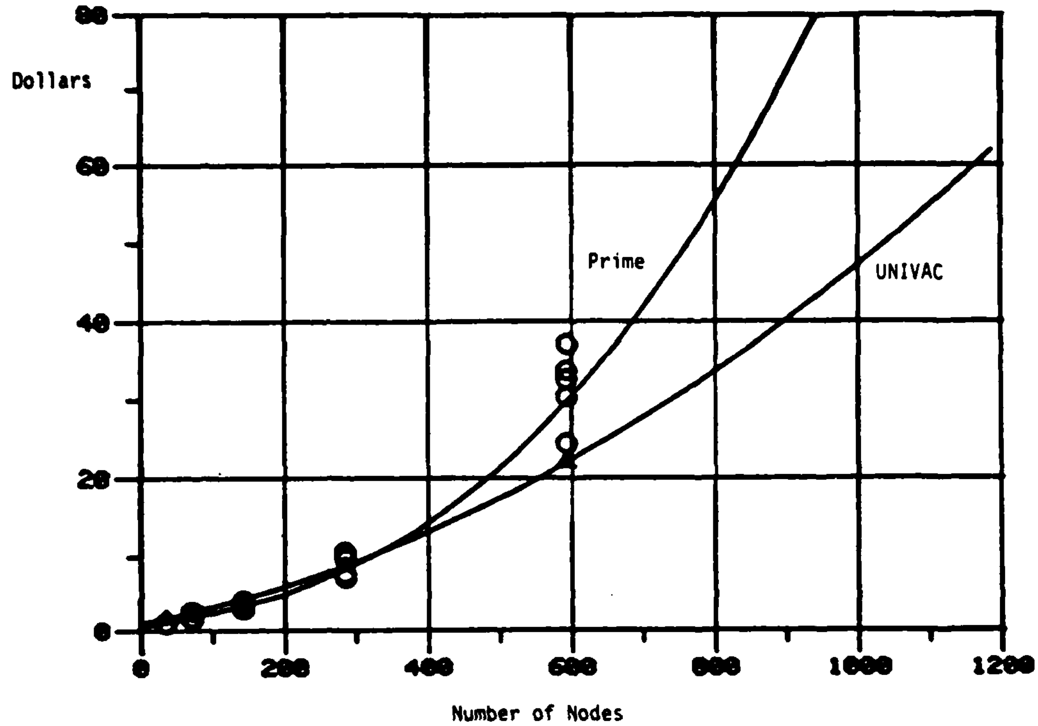

Fig. 3 - Comparison of total cost for plate problem using the SPAR program

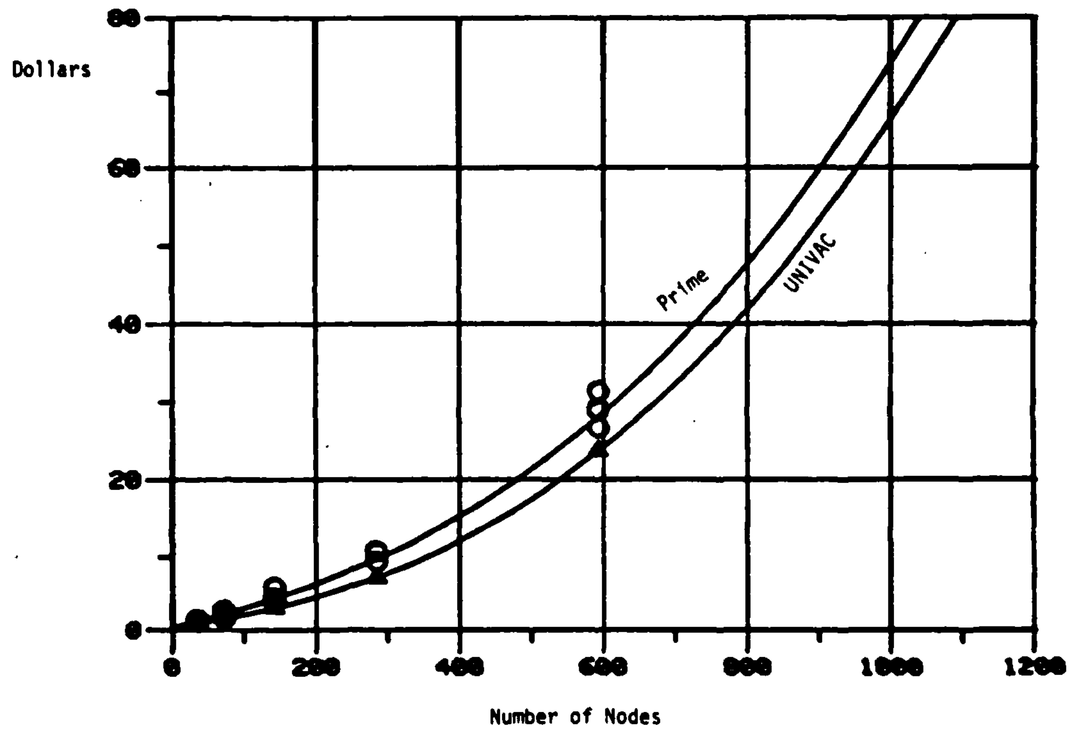

Fig. 4 - Comparison of total cost for plate problem using the SAP IV program

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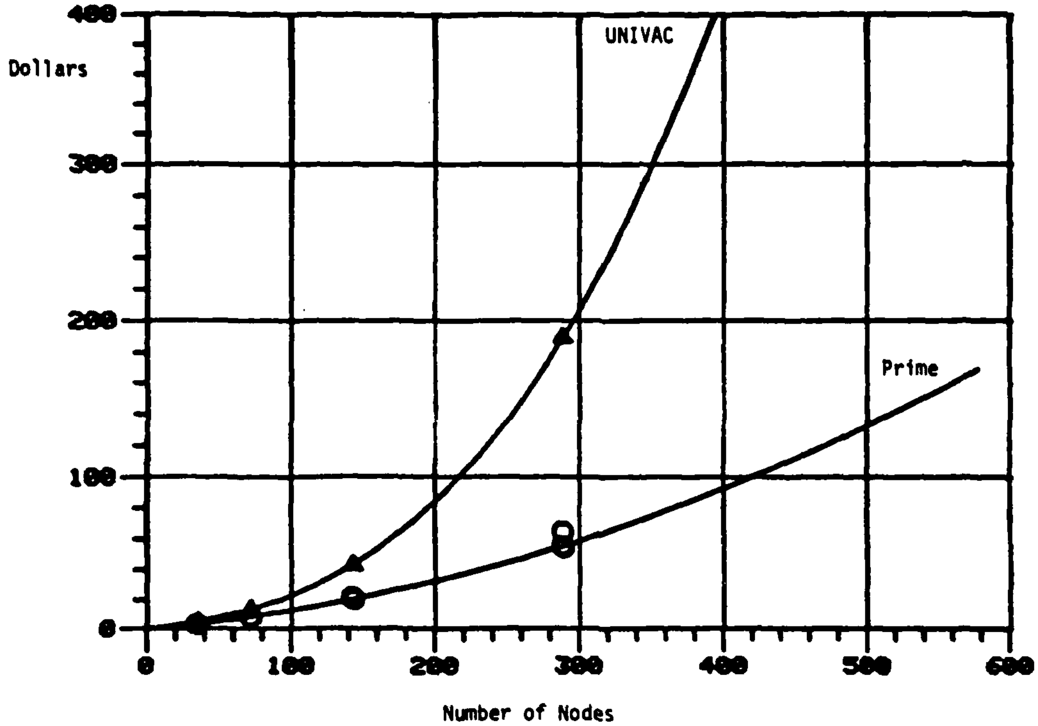

Fig. 5 - Comparison of total cost for plate problem using the TWODEL program

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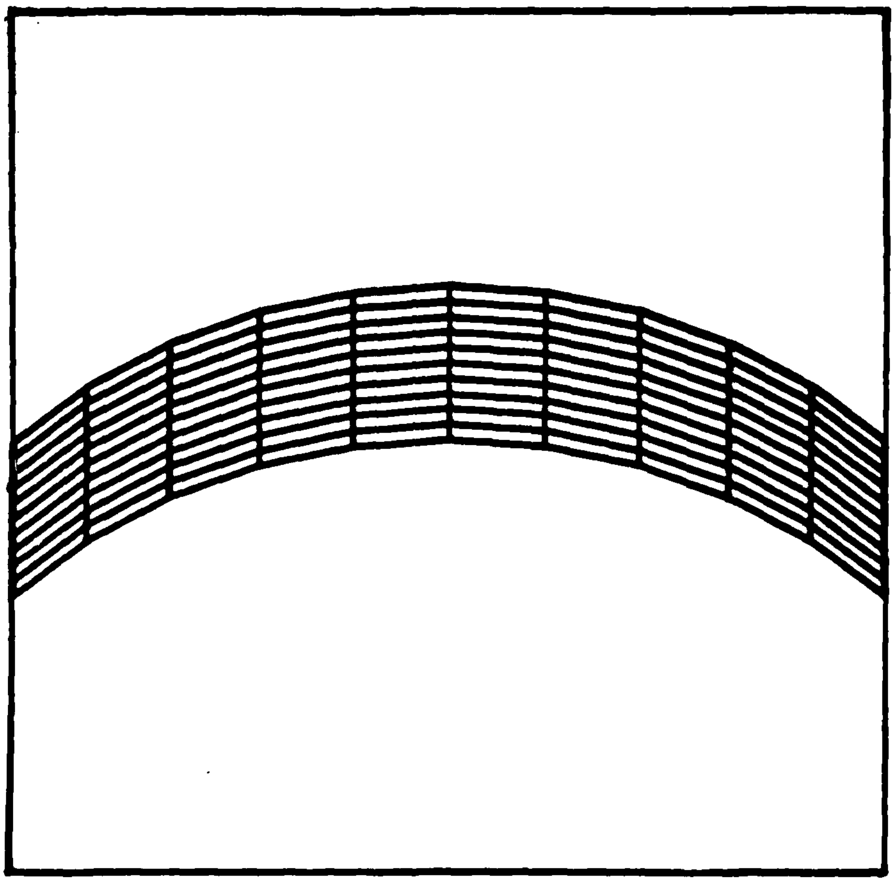

Fig. 6 - A typical cylinder model

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